Focusing Solenoids for HINS Linac Front End and PXIE Test Stand: Alignment Studies

Participants:

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HINS Linac Front End

	MEBT / RT CH	SSR-1	SSR-2
Number of solenoids in the section	19 (3 + 16)	18 (9 x 2)	6
Parameter			
Bore diameter	20 mm	30 mm	30 mm
Bore type	warm	cold	cold
Field Integral FI = $\int B^2 dl$ ($T^2 \cdot cm$)	180	300	500
Margin	30%	30%	30%
Leff (cm) @ Bm	< 10 cm		
Field extension	< 2*Leff	Sharp edges	Sharp edges
Cryostat type	Stand alone	Integrated	Integrated
Cold mass length (mm)	130	219	294

Alignment requirements:

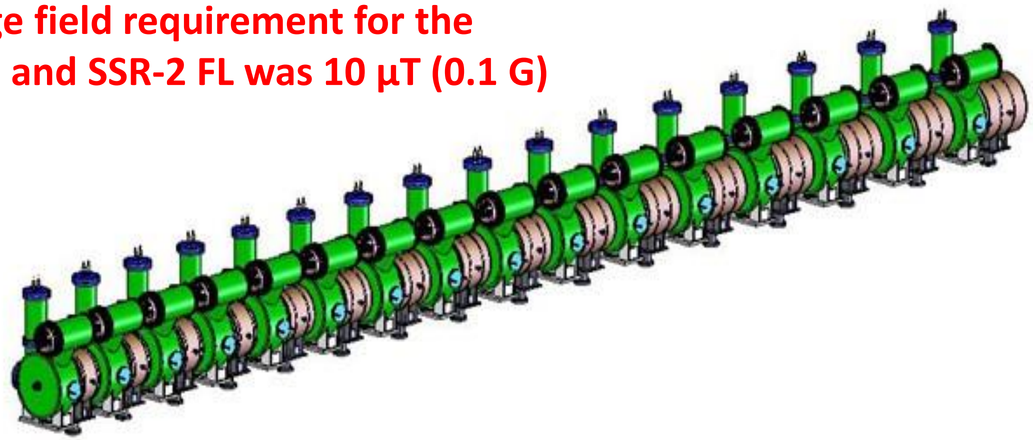
NC cavities (RT section) - 0.5 mm max.

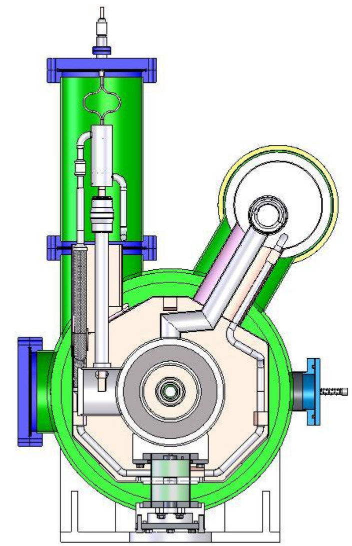
SC spoke cavities - 0.5 mm max.

Solenoid end displacement - 0.3 mm max

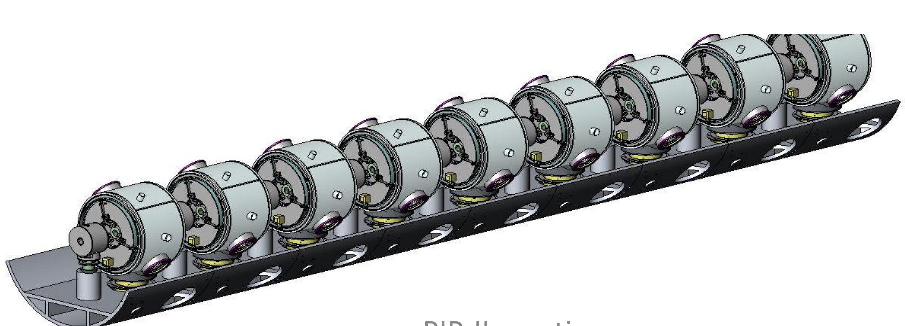
Fringe field requirement for the SSR1 and SSR-2 FL was 10 μT (0.1 G)

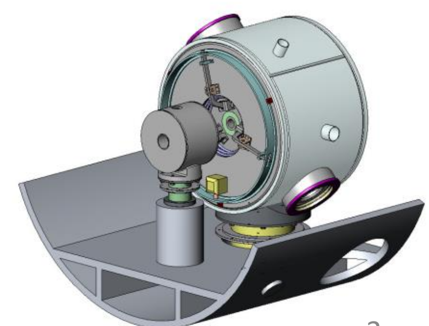
RT section



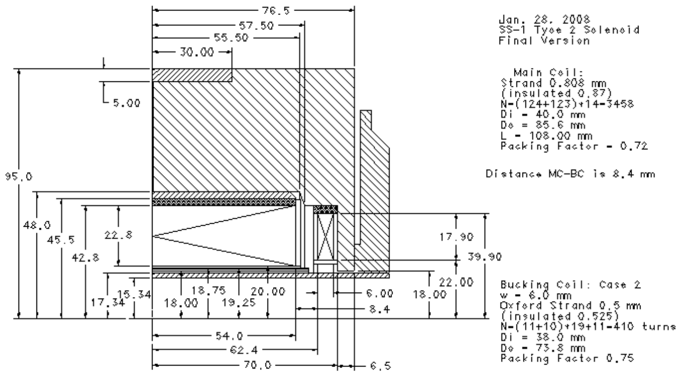


Superconducting section (SS-1)



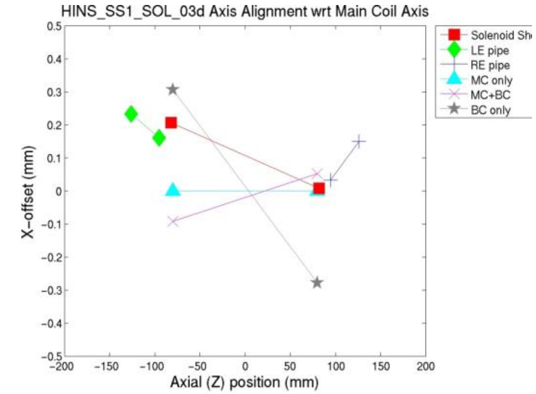


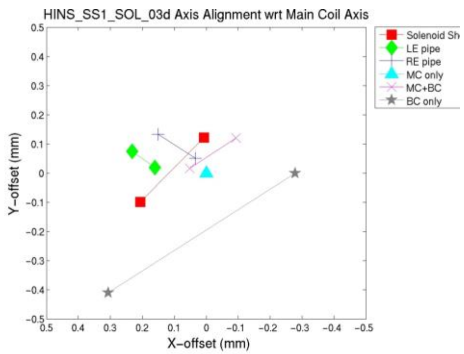
HINS linac cryomodules: magnetic axis relative position

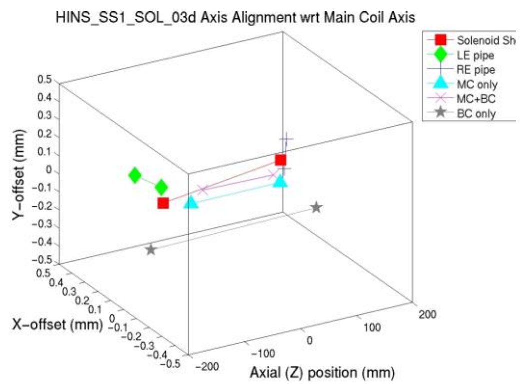


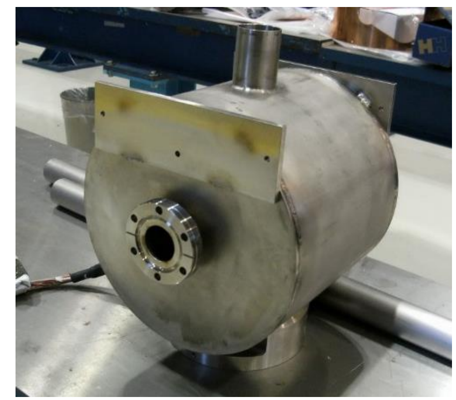
FNAL, HINS linac SSR1 FL

- Stretched wire measurements at RT using different modes of excitation
- Optical measurements based on mechanical features of lenses

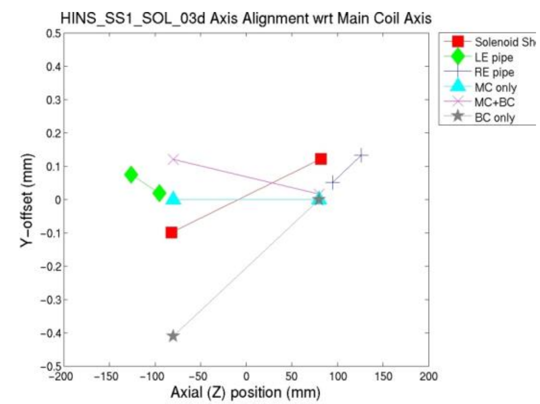








1. Uncertainty of VW method is ~20 um.
2. Uncertainty of optical referencing is ~50 um.
3. Statistics is poor
4. 0.2 mm magnetic axis drift after LH welding →



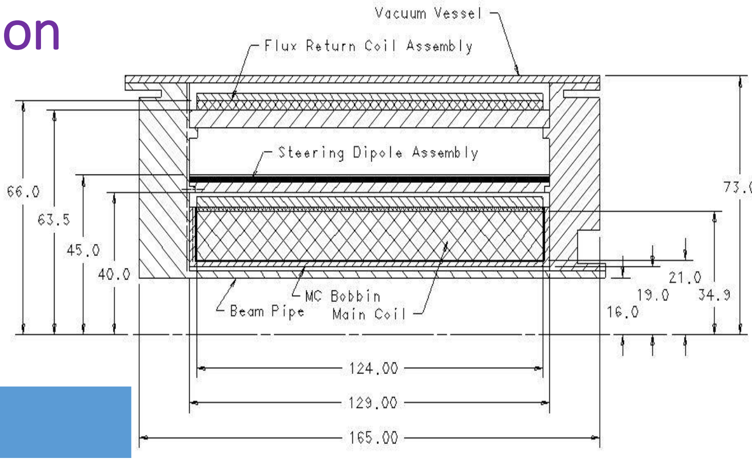
For this design one cannot rely on the mechanical features for alignment - magnetic axis must be measured! →
A special cryomodule for certification of lenses is needed.

PXIE cryomodules: magnetic axis relative position

PXIE SSR1 FL

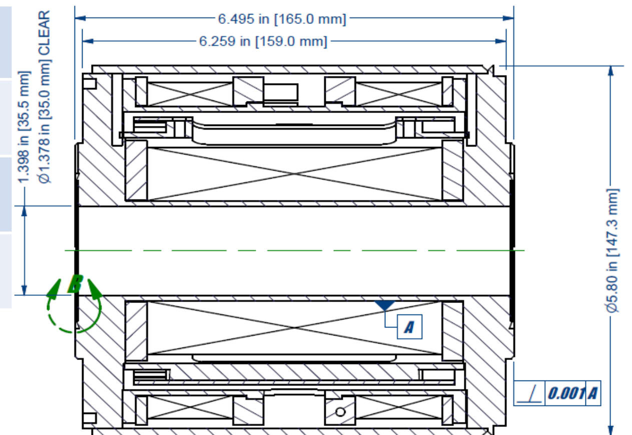
0.1 mm RMS

Design goals:
1. Precision positioning of the windings.
2. Mitigate after-welding deformation.



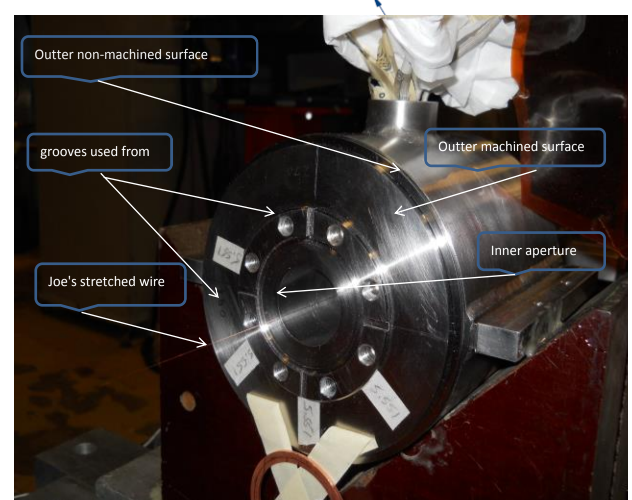
Magnetic axis relative position in the SSR1 and in HW prototype lenses (Cryomagnetics Inc. data)

		Y = -64 mm	Y = +64 mm
HW Cryomodule	ΔX	-0.28	-0.12
	ΔZ	+0.16	+0.25
SSR1 Cryomodule	ΔX	-0.093	-0.024
	ΔZ	-0.054	-0.135



Magnetic axis position in the SSR1 prototype lens measured by FNAL and @ Cryomagnetics Inc.

		Y = -82.5 mm	Y = +82.5 mm
FNAL	ΔX	0	-0.05
	ΔZ	+0.15	+0.05
Cryomagnetics	ΔX	-0.1	-0.014
	ΔZ	-0.043	-0.146



PXIE SSR1 cryomodule: magnetic axis relative position

Magnetic axis position in the SSR1 production #1 lens before and after welding operation (measured by FNAL)

		Y = -80 mm	Y = +80 mm
Before welding	ΔX	-0.29 ± 0.1	+0.05 ± 0.04
	ΔZ	-0.22 ± 0.025	+0.06 ± 0.04
After welding	ΔX	-0.26 ± 0.06	+0.0175 ± 0.030
	ΔZ	-0.115 ± 0.015	+0.146± 0.012

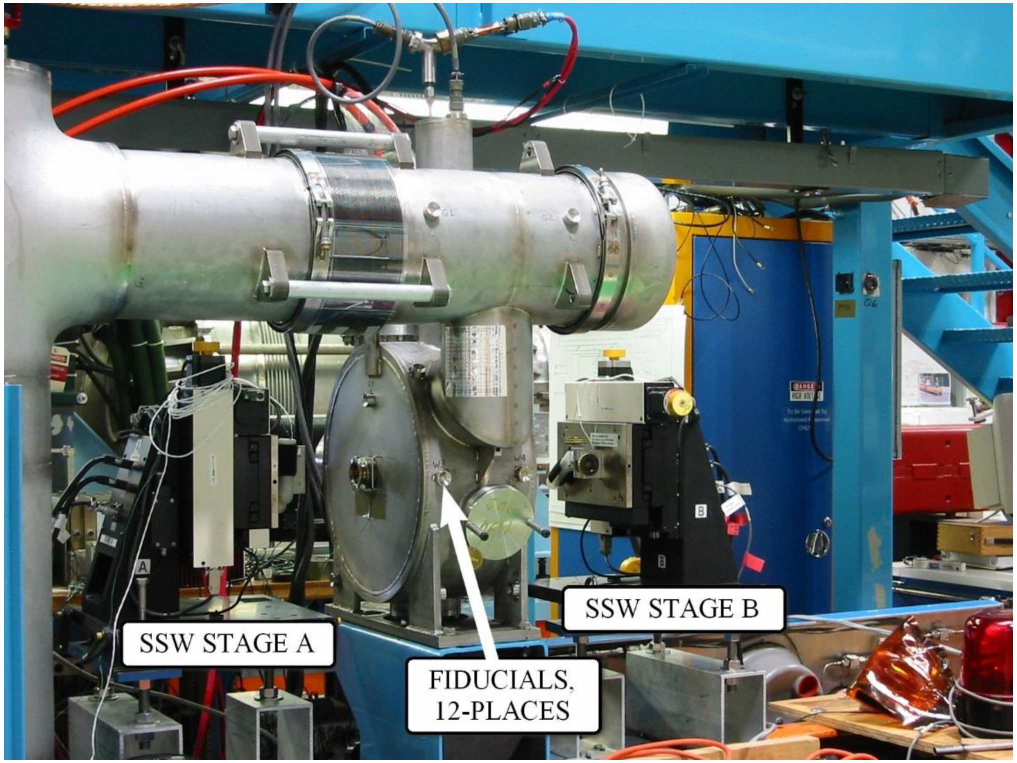
Effective shift of the magnetic axis after welding: vertically by ~0.1 mm

Requirements for the cryomodule: 0.5 mm RMS and 1 mrad RMS

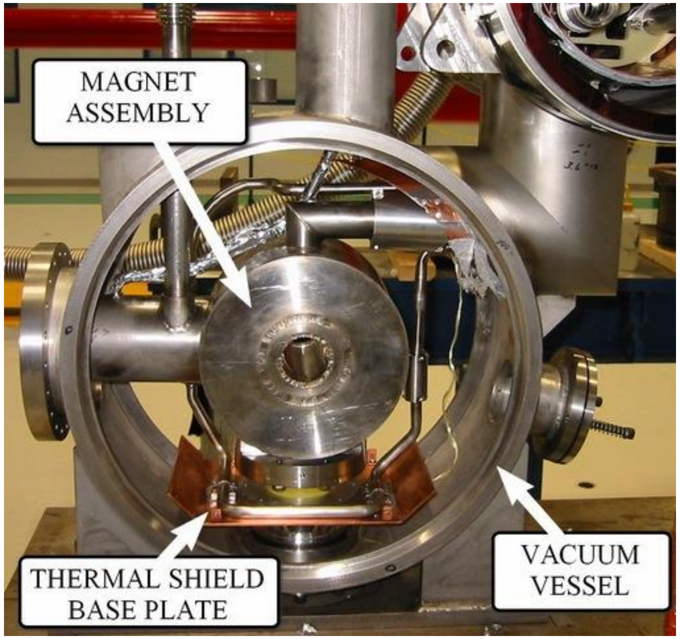
Prototype SSR1 lens TD-14-004
Production #1 SSR1 lens TD-15-011
Production Summary TD-15-021

What is magnetic axis?
How its position depends on the method used for the measurements?
What a right method?

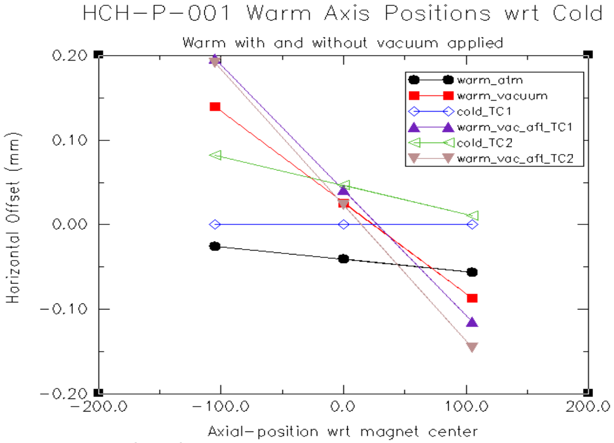
HINS Linac: RT Section Solenoid Alignment



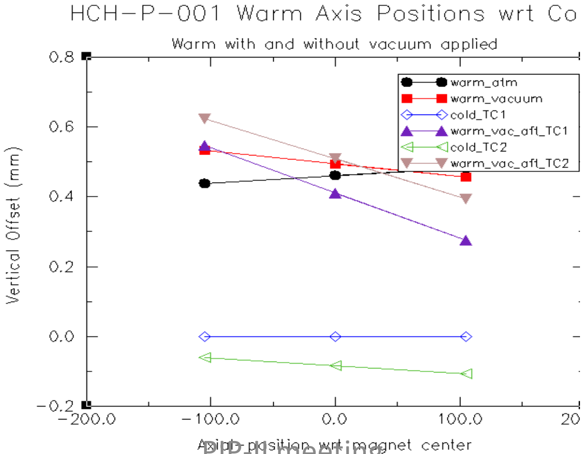
Warm measurement repeatability ~10-20 um
Cold measurement repeatability ~10 um

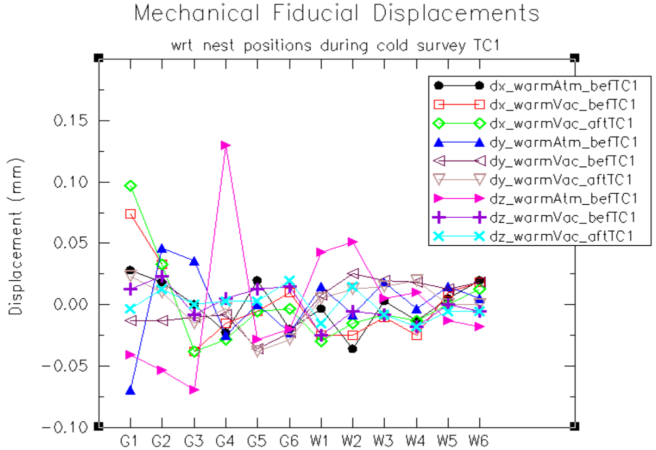


X direction

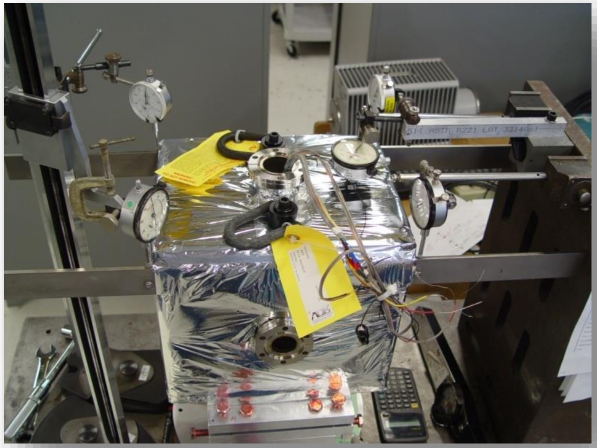


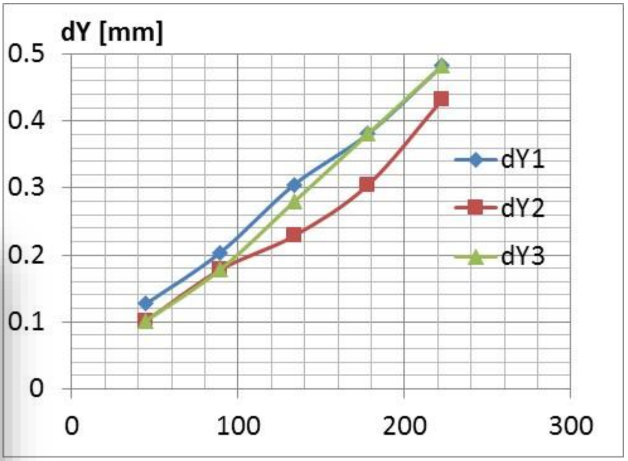
Z direction

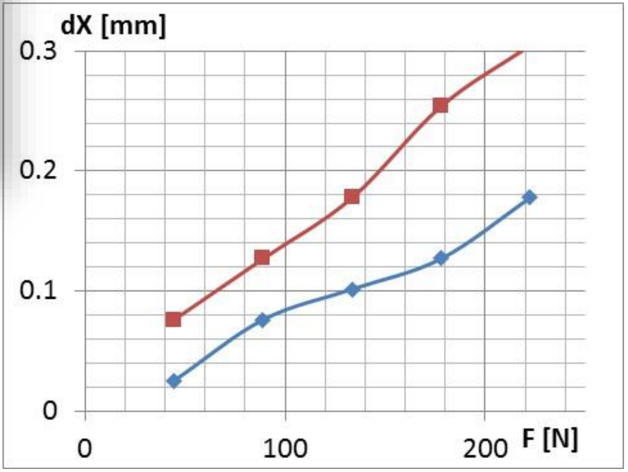




HINS Linac SS1 Focusing Lens Prototyping





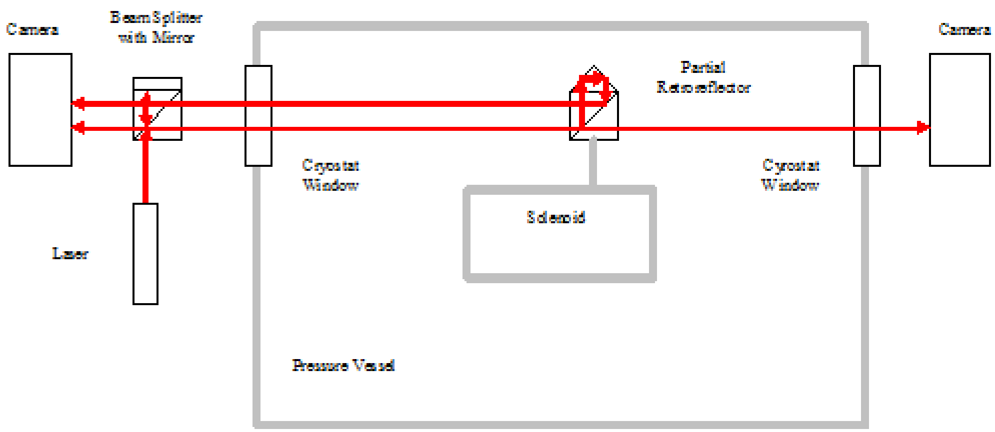


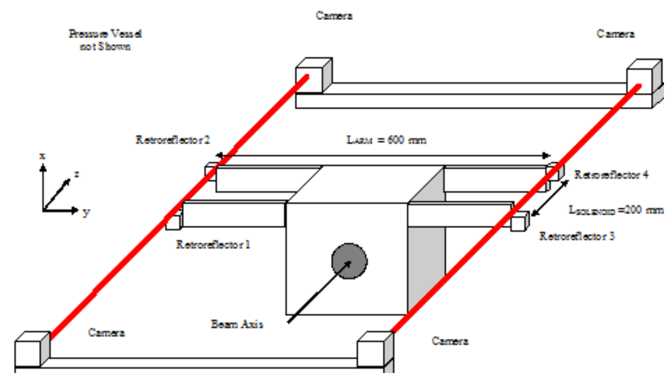
Having in mind the modest rigidity of the assembly, a way how the lenses are assembled in the cryomodule (using three 40 mm bellows), and tight alignment requirements, a reliable way to follow position of each focusing lens in the assembled cryomodule needs to be found and as well as a way of correcting the position in-situ.

Tracking position of beam line elements in a cryomodule.

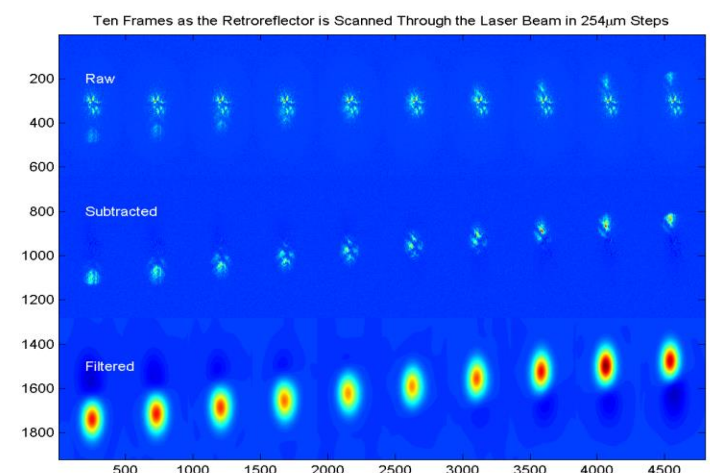
BPM-based system (DESY 2000-s, SLAC 1980-s)
- Requires long stretched wire – sag.
- Each element in the beamline requires three BPM-s – space, weight, cost.
- Achievable accuracy is not great (~0.1 mm).

Laser-based alignment systems can potentially provide better accuracy and flexibility. Long base can be a problem. Long base optical alignment and monitoring concept was developed and tested





Component	Displacement Error (um)	Parallelism (mrad)	Z (m)	Parallism Error (um)	Tilt (mrad)	Thickness (mm)	Displacement Due To Tilt (um)	Combined Error (um)
Camera	5		0	0			0	**5**
Stage	2		0	0			0	**2**
Optical Window		0.3	0.05	29	1	25	8	**30**
Corner Cube		0.005	0.75	4	1	12	4	**6**
Optical Window		0.3	1.45	29	1	25	8	**30**
Stage	2		1.5	0			0	**2**
Camera	5		1.5	0			0	**5**
Total	**8**			**41**			**12**	**44**



Tracking position of beam line elements in a cryomodule.

TD-09-015

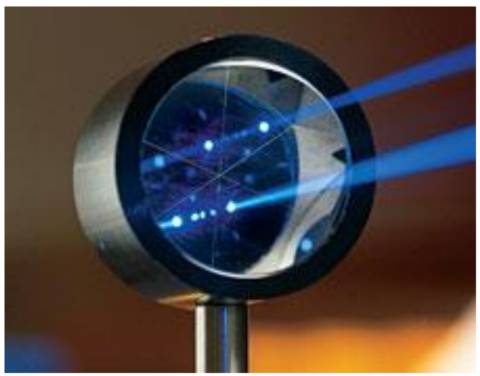
First Tests of a Prototype Optical System for the HINS Focusing Solenoid Alignment Study

Warren Schappert
Test and Instrumentation Department
Technical Division
Fermilab

August 30, 2009

Alignment Laser

Corner Reflector

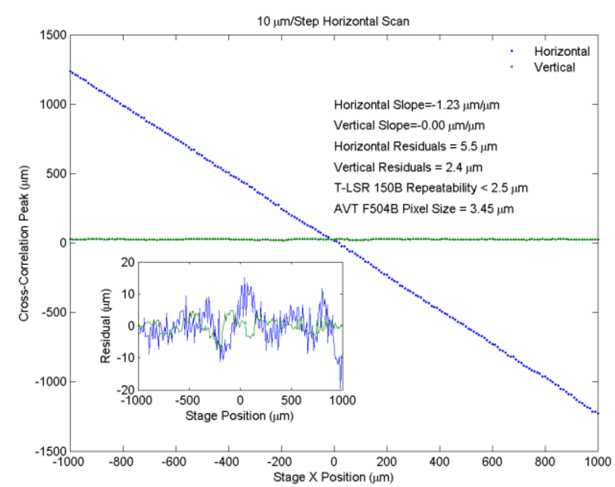


Beam Splitter

Camera

Second Prototype

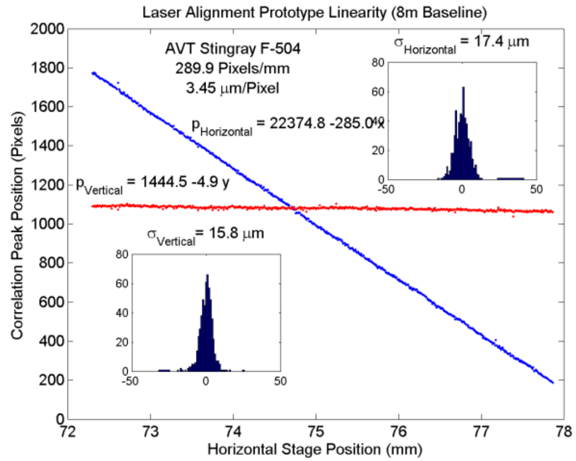
- Design
  - Wire cross-hair target
  - **Diffraction pattern** used to identify beam center
- Advantages
  - No active components
  - Radiation hard
- Disadvantages
  - Beam center determination at long range?
  - Interference between multiple targets
- Results
  - Excellent resolution and linearity over 1.5 m baseline (σ<6 μm)
  - Uncertainties in scaling → **long base prototyping**

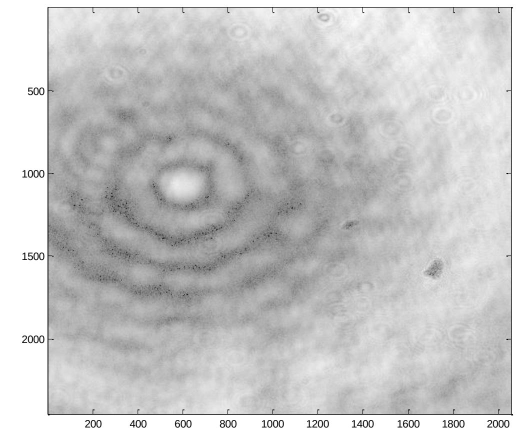


Tracking position of beam line elements in a cryomodule.

Third Prototype

- Design
  - Ball bearing target produces Poisson spot
- Advantages
  - Passive
  - Radiation hard
  - Long range possible
- Disadvantages
  - Interference between multiple targets
- Results
  - Good resolution and linearity (σ<18 μm) over 8m baseline





THE POISSON LINE AS A STRAIGHT LINE REFERENCE

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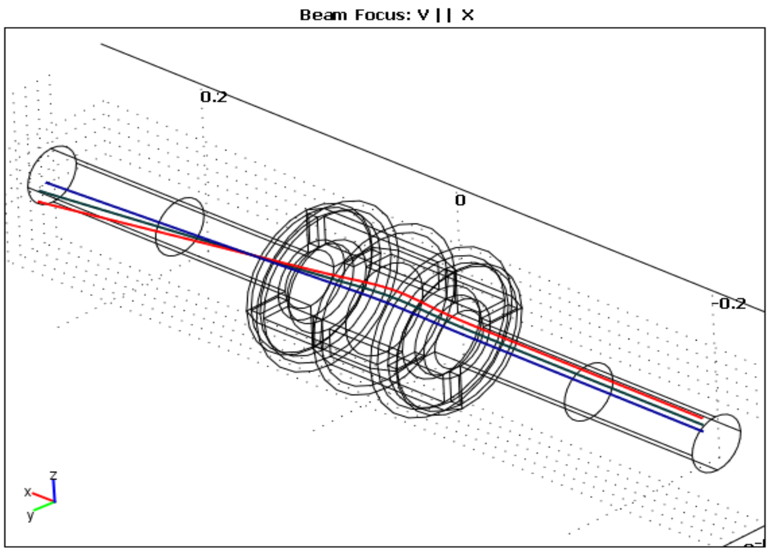
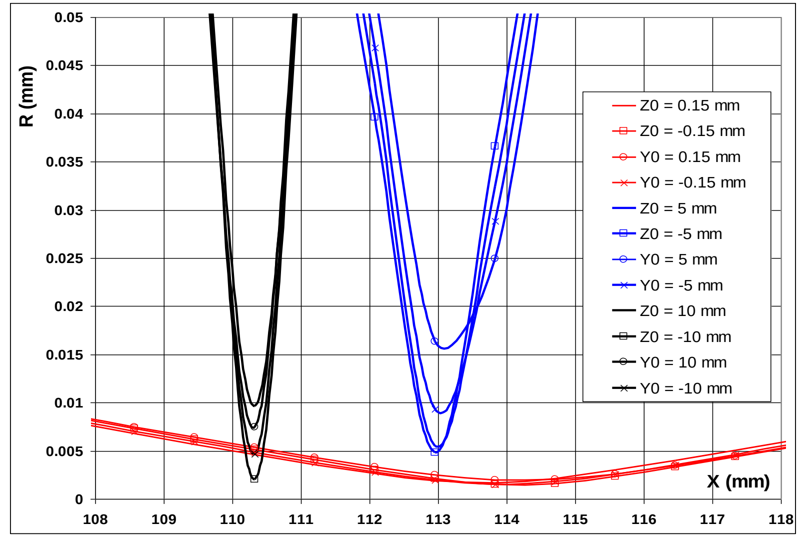
Other Poisson Spot Alignment Studies

- First proposed by Lee Griffith at LBL in 1987
- Studies for APS at Argonne
  - Horst Freidsam (now at FNAL PPD)
- Recent studies at DESY for XFEL
  - σ= 12 μm over 5m baseline

What does proton beam see?

In the “perfect” lens, magnetic axis coincides with the optical axis.
Nevertheless, the “perfect” lens **does have** spherical aberrations.





[What is magnetic axis](#)?
How what is found depends on the method used for the measurements?
What a right method?

$$f = \frac{8 \cdot \frac{m}{q} \cdot U}{\int_{-\infty}^{+\infty} B_X^2 \, dX}$$

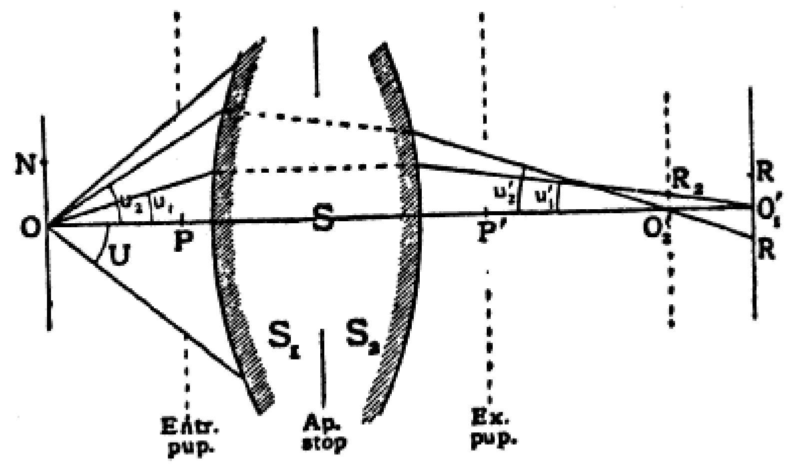


FIG. 5.

Summary

Limited studies were made to identify possible problems with alignment of beam line elements and find ways to resolve known problems.

The results of the studies indicate that the alignment requirements for the PXIE SSR1 cryomodule can be met during initial installation, but just marginally.